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MEMORANDUM FOR IN-HOUSE PUBLICATIONS

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SUBJECT: Authorization for Release of Technical Information, Control Number: AFRL-PR-ED-TP-1998-169 Tim Miller "Mode Mixity Determinations for Interfacial Cracking in Incompressible Materials Under Plane Strain Conditions (Presentation for paper AFRL-PR-ED-TP-1998-075 cleared 5 May 98)

Presentation Only **(Statement A)**

Mode Mixity Determinations for Interfacial Cracking in Incompressible Materials Under Plane Strain Conditions

T.C. Miller

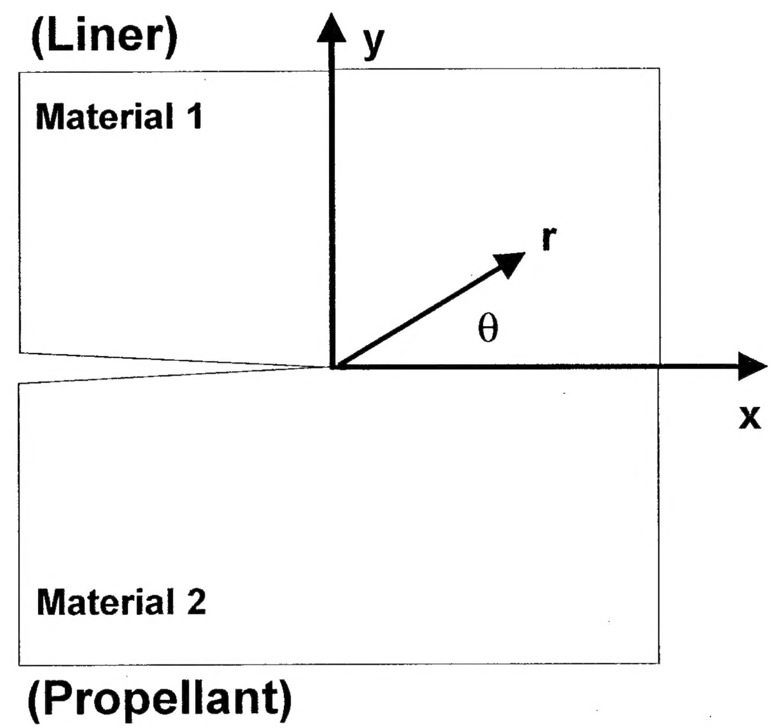
Air Force Research Laboratory
Edwards Air Force Base, California

October 1998

Introduction

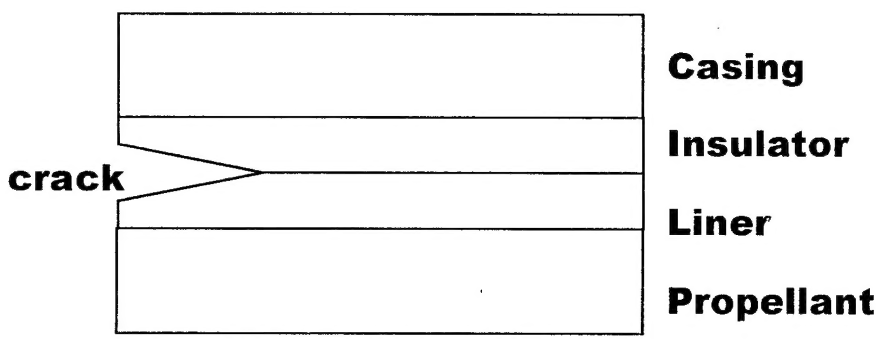
Liner - Propellant Failures

1. Materials are Incompressible
2. Plane Strain Conditions Exist
3. E_2/E_1 Varies with Materials Used

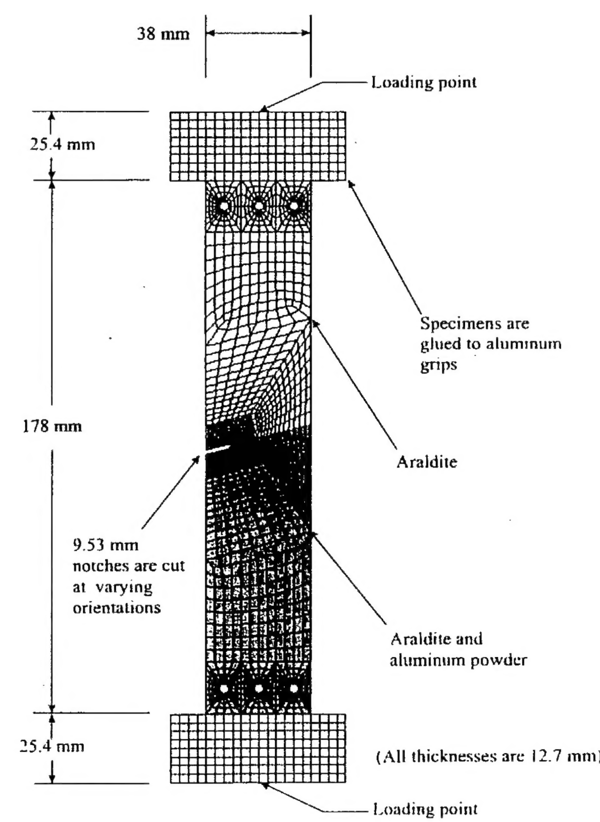


Specimen Geometry and Related Application

Applications to Composite Structures



Related Photoelastic Stress Freezing Experiments



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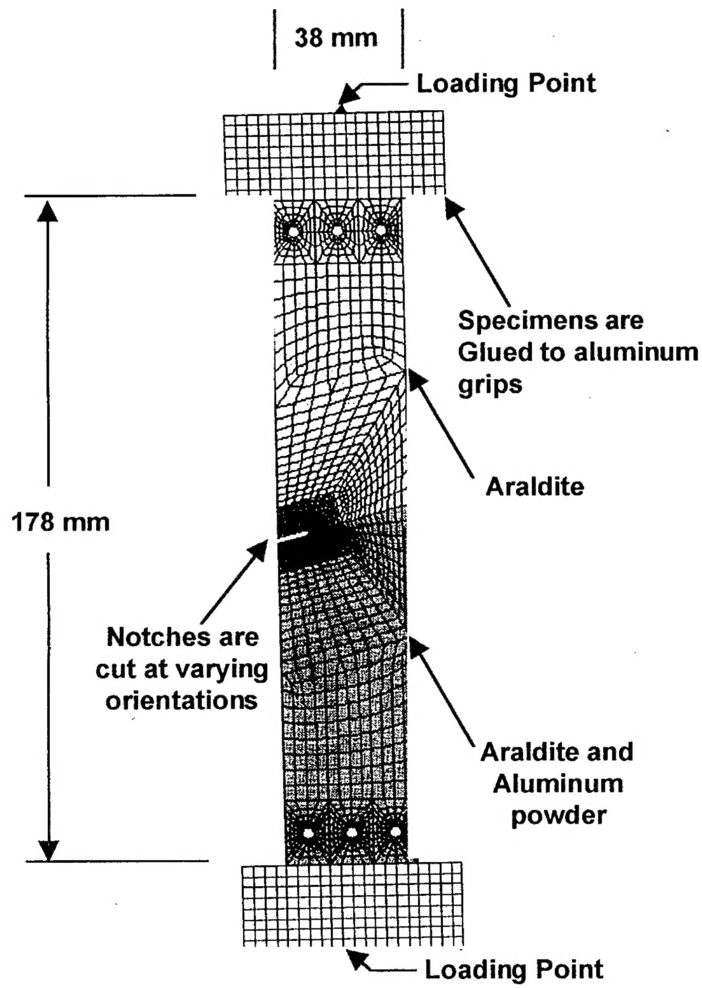
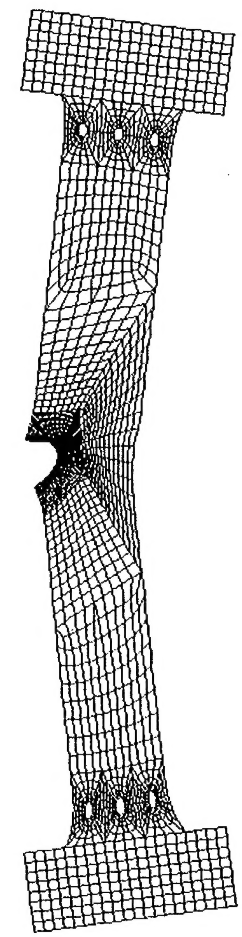
Modeling of Incompressible Bimaterials Under Plane Strain Conditions



Typical Finite Element Model - Crack Orientation = 15 Degrees

- Both homogeneous and bimaterial specimens are considered
- Mode mixity is varied by changing crack angle (0, 15, 30, 45 degrees).



Loaded Specimen in Deformed Configuration

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Incompressible Bimaterial Pans Under Plane Strain Conditions

General Interfacial Fracture

$\epsilon \neq 0 \qquad \beta \neq 0$

$$\sigma_{pq} = \frac{1}{\sqrt{2\pi r}}\{Re(\boldsymbol{K} r^{i\epsilon})\Sigma^{I}_{pq}(\theta) + Im(\boldsymbol{K} r^{i\epsilon})\Sigma^{II}_{pq}(\theta)\}$$

$$(\sigma_{yy} + i\sigma_{xy})_{\theta=0} = \frac{\boldsymbol{K} r^{i\epsilon}}{\sqrt{2\pi r}} = \frac{K_1 + iK_2}{\sqrt{2\pi r}}\,[\cos(\epsilon Lnr) + i\,\sin(\epsilon Lnr)]$$

$$J = G = \frac{\Lambda_1 + \Lambda_2}{16\cosh^2(\pi\epsilon)}\,|K|^2$$

Plane Strain/Incompressible Materials

$\epsilon = 0 \qquad \beta = 0$

$$\sigma_{pq} = \frac{1}{\sqrt{2\pi r}}\{Re(\boldsymbol{K})\Sigma^{I}_{pq}(\theta) + Im(\boldsymbol{K})\Sigma^{II}_{pq}(\theta)\}$$

$$(\sigma_{yy} + i\sigma_{xy})_{\theta=0} = \frac{\boldsymbol{K}}{\sqrt{2\pi r}} = \frac{K_1 + iK_2}{\sqrt{2\pi r}}$$

$$J = G = \frac{K^2}{\overline{E^*}}, \qquad \frac{1}{\overline{E^*}} = \frac{1}{2}\left[\frac{1}{\overline{E_1}} + \frac{1}{\overline{E_2}}\right], \qquad \overline{E_1} = \frac{E_1}{1 - \nu_1^2}, \qquad \overline{E_2} = \frac{E_2}{1 - \nu_2^2}$$

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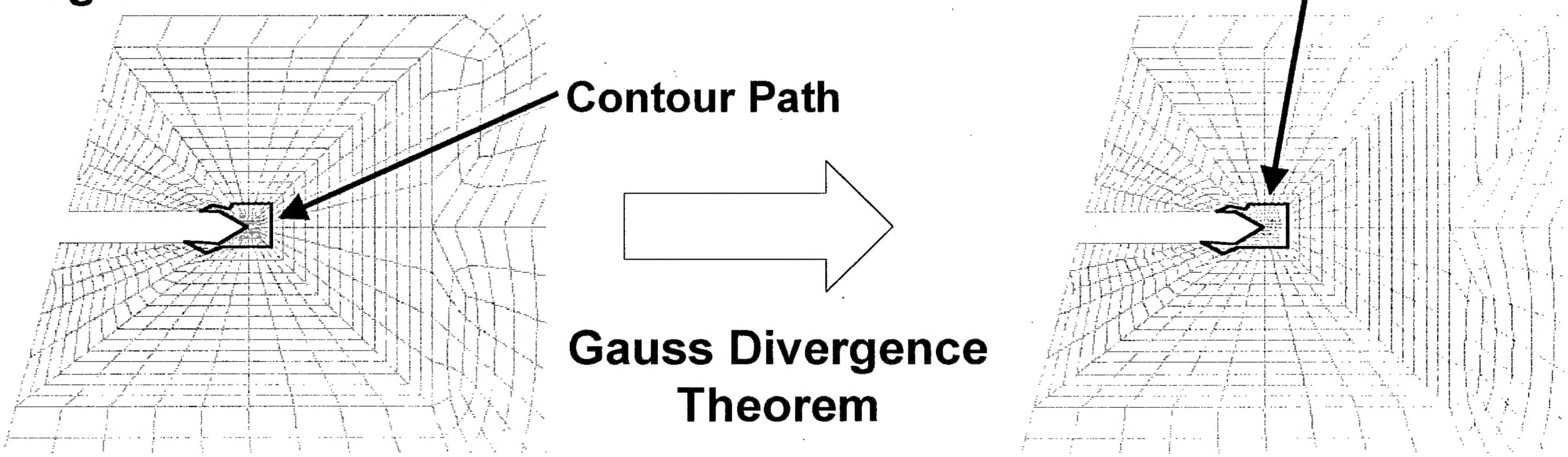
Method for Characterizing Complex Stress Intensity Factor in Bimaterial Problems

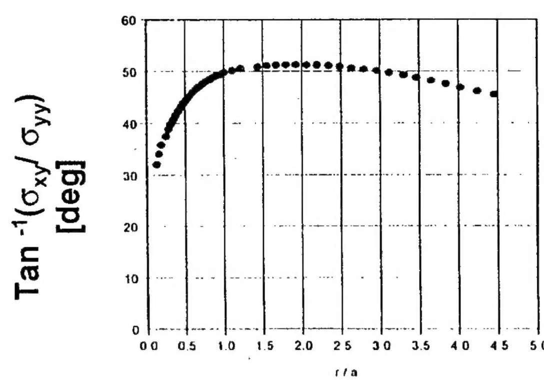
Magnitude Assessment

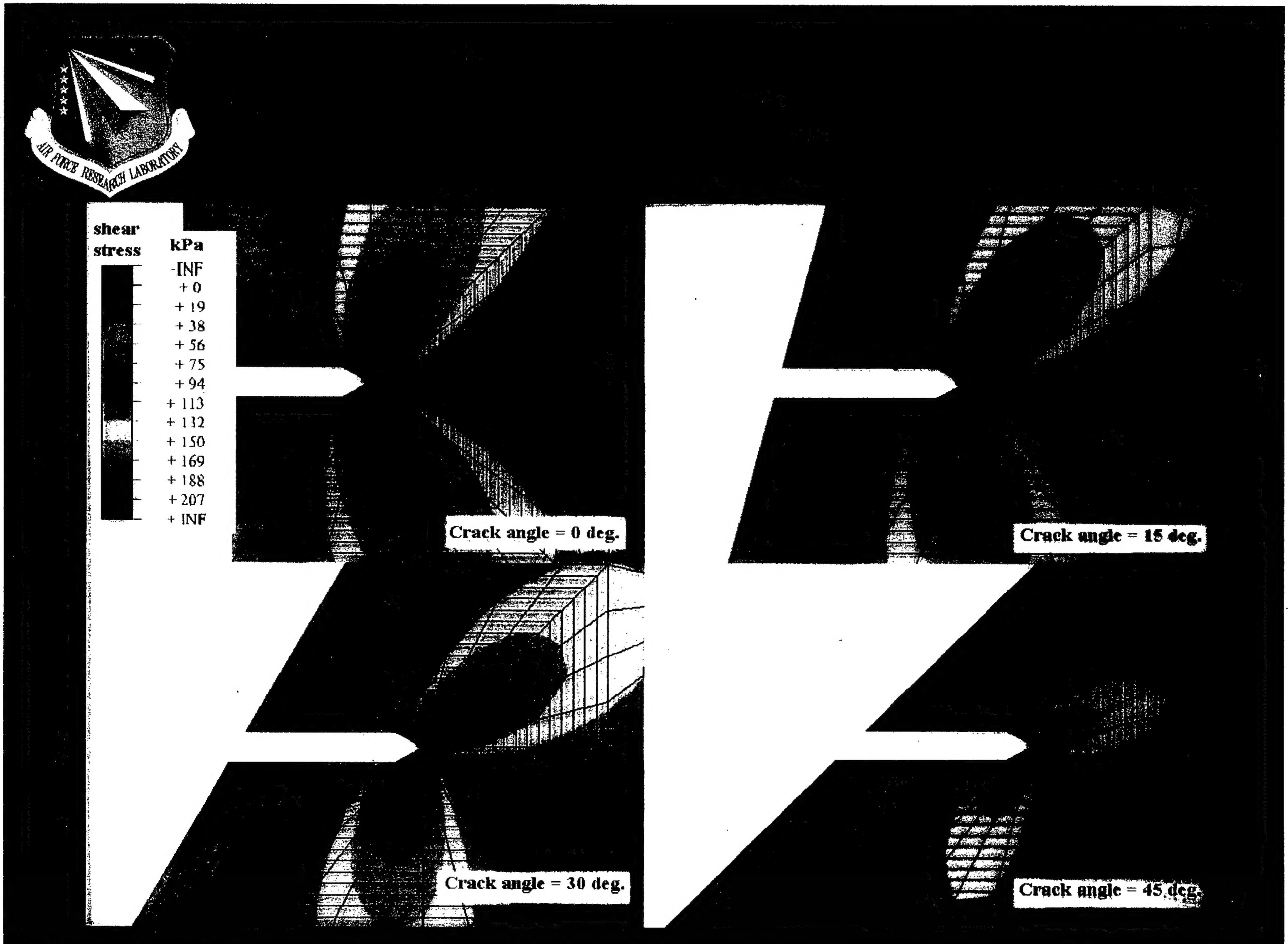


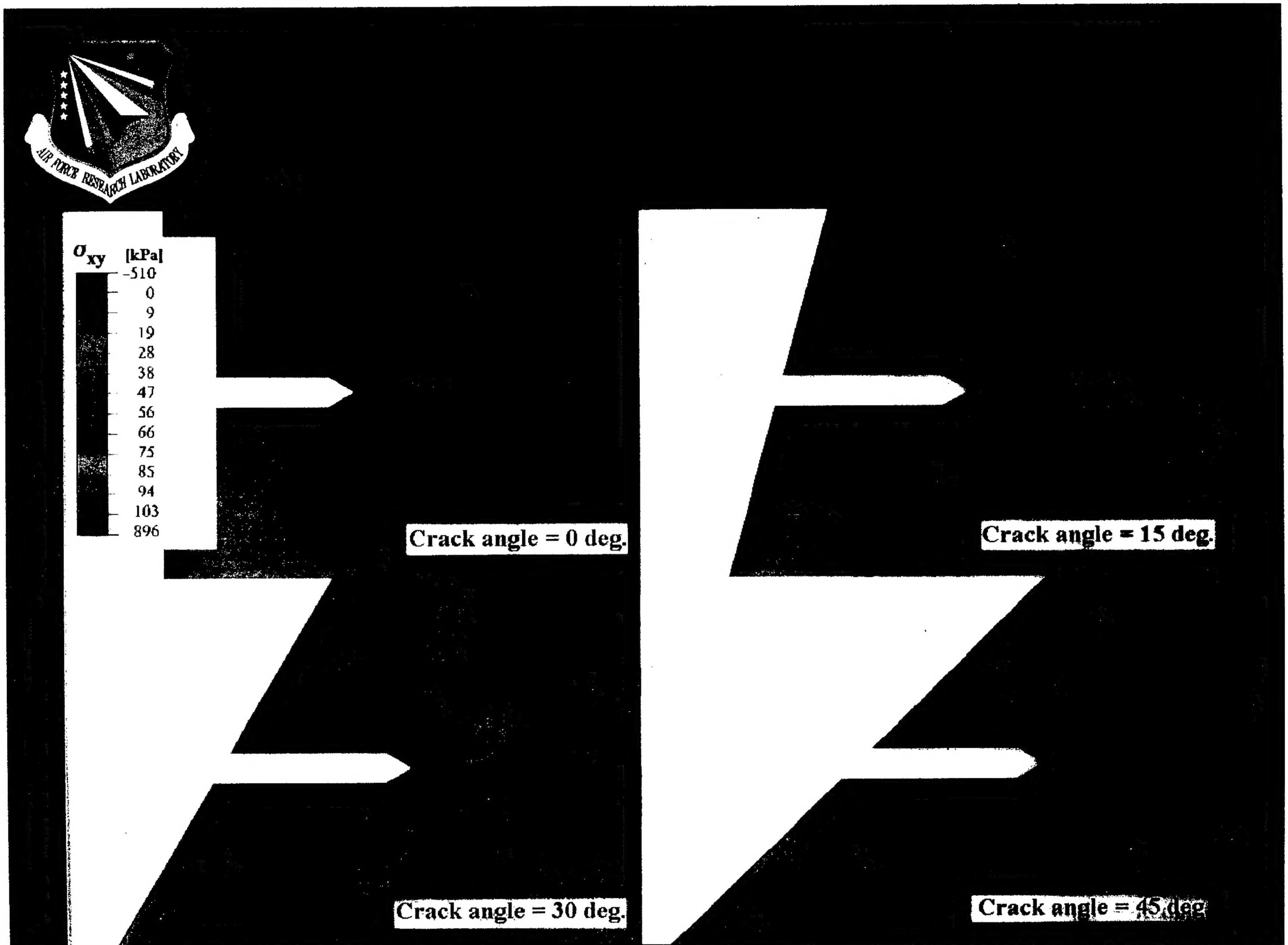
J as Contour Integral | **J as Equivalent Area Integral**

$J = \int_A[\sigma_{ij}\, u_{j,1} - wd_{1i}]q_{1,i}\, dA$, $|K| = \sqrt{J\overline{E}^*}$, $\overline{E}^*$ = Effective plane strain modulus, $1/\overline{E}^* = 1/2\,(1/\overline{E}_1 + 1/\overline{E}_2)$

- T_{xy} and T_{yy} Averaged at Nodes Along y = o
- $\psi(r/a)$ is Cubic Fit of $\tan^{-1}[(T_{xy}/T_{yy})_{\theta=o}]$ vs. r/a
- $\Psi \equiv \tan^{-1}\left(\frac{K_{II}}{K_{II}}\right) = \lim_{r/a \to o} \psi(r/a)$




AIR FORCE RESEARCH LABORATORY
shear stress
kPa
-INF
+ 0
+ 19
+ 38
+ 56
+ 75
+ 94
+ 113
+ 132
+ 150
+ 169
+ 188
+ 207
+ INF
Crack angle = 0 deg.
Crack angle = 15 deg.
Crack angle = 30 deg.
Crack angle = 45 deg.



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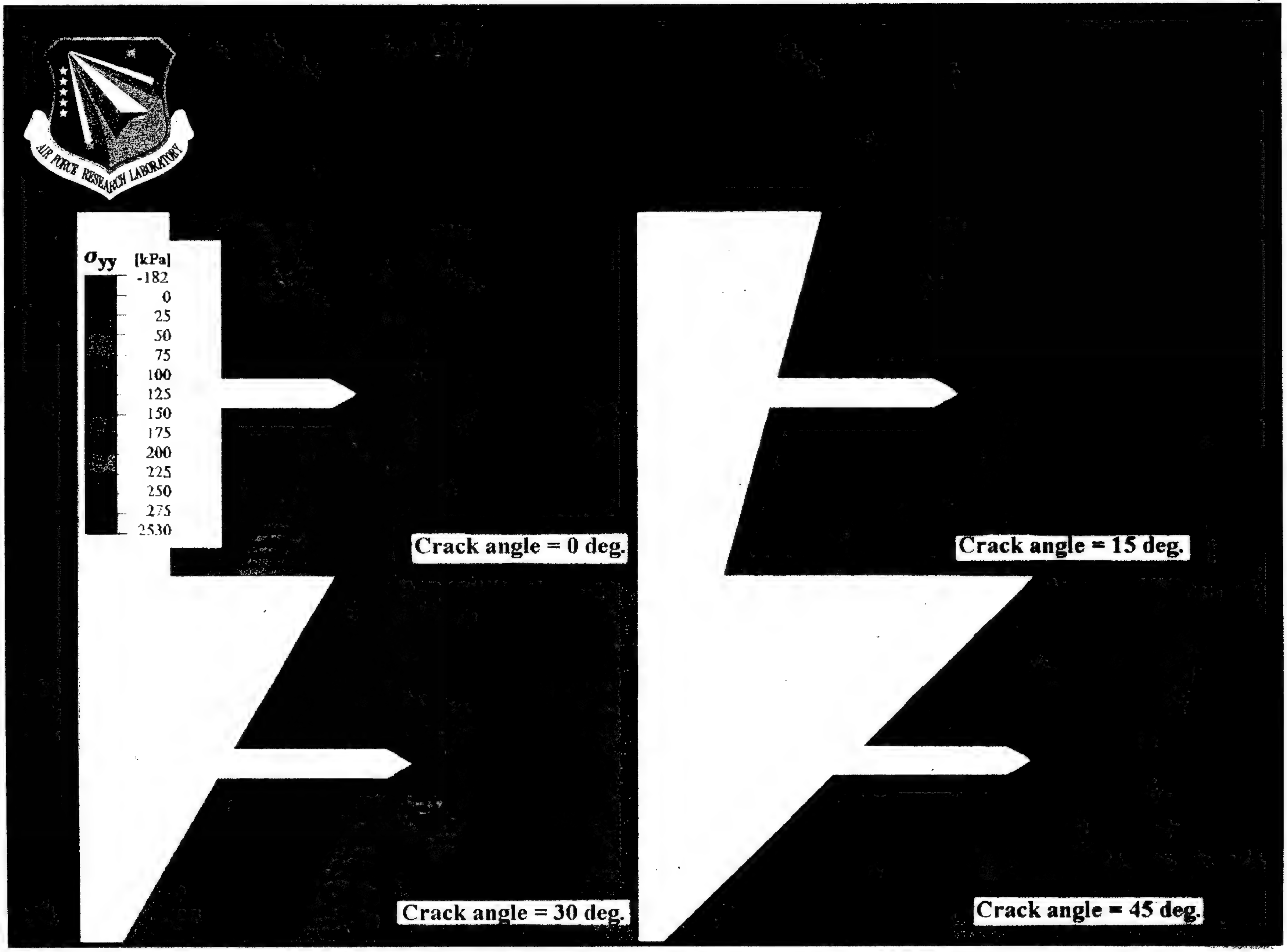
σ_{xy} [kPa]
-510
0
9
19
28
38
47
56
66
75
85
94
103
896
Crack angle = 0 deg.
Crack angle = 15 deg.
Crack angle = 30 deg.
Crack angle = 45 deg.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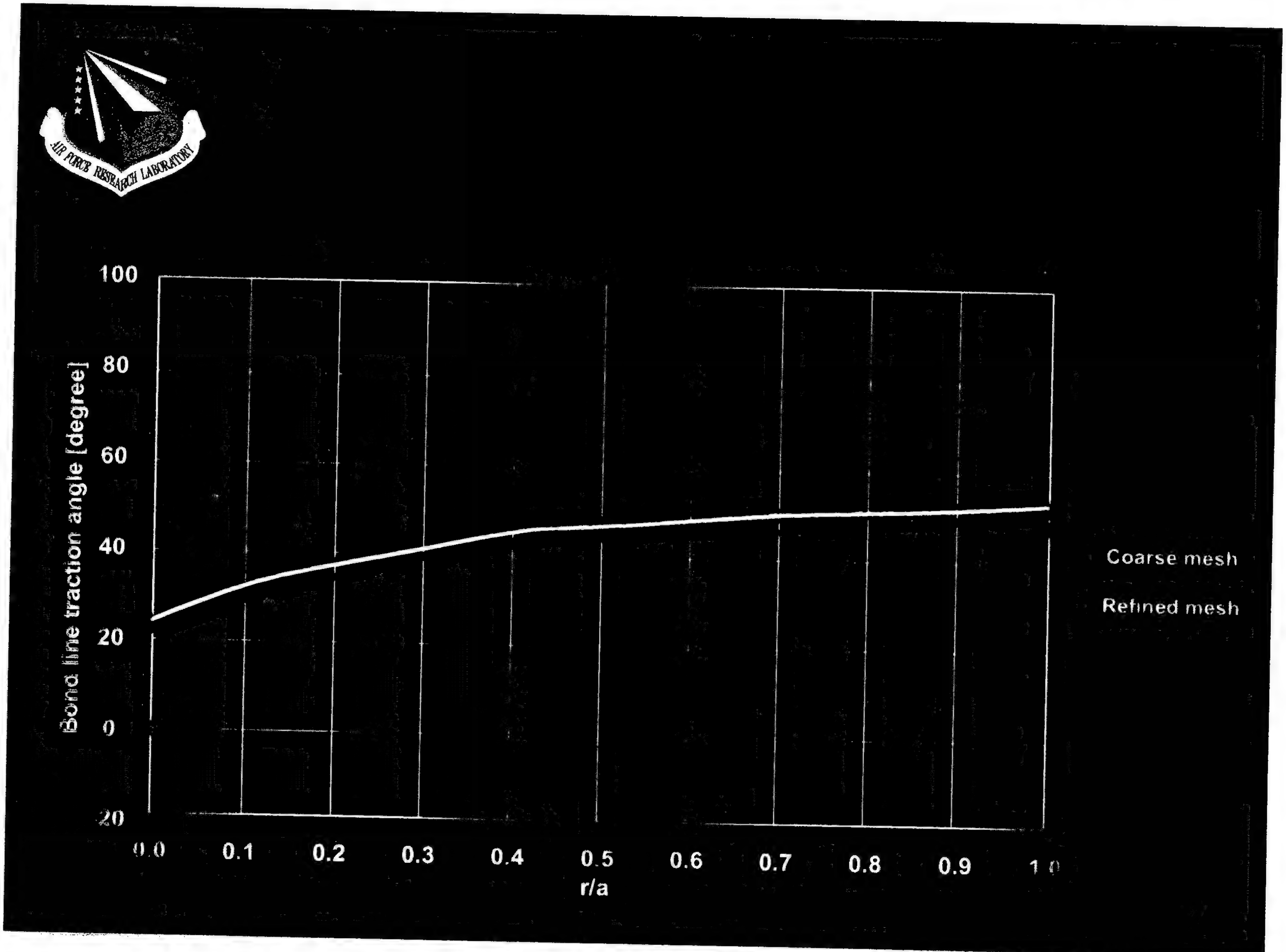
σ_{yy} [kPa]
-182
0
25
50
75
100
125
150
175
200
225
250
275
2530
Crack angle = 0 deg.
Crack angle = 15 deg.
Crack angle = 30 deg.
Crack angle = 45 deg.



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100
80
60
40
20
0
-20
Bond line traction angle [degree]
0.0
0.1
0.2
0.3
0.4
0.5
0.6
0.7
0.8
0.9
1.0
r/a
Coarse mesh
Refined mesh

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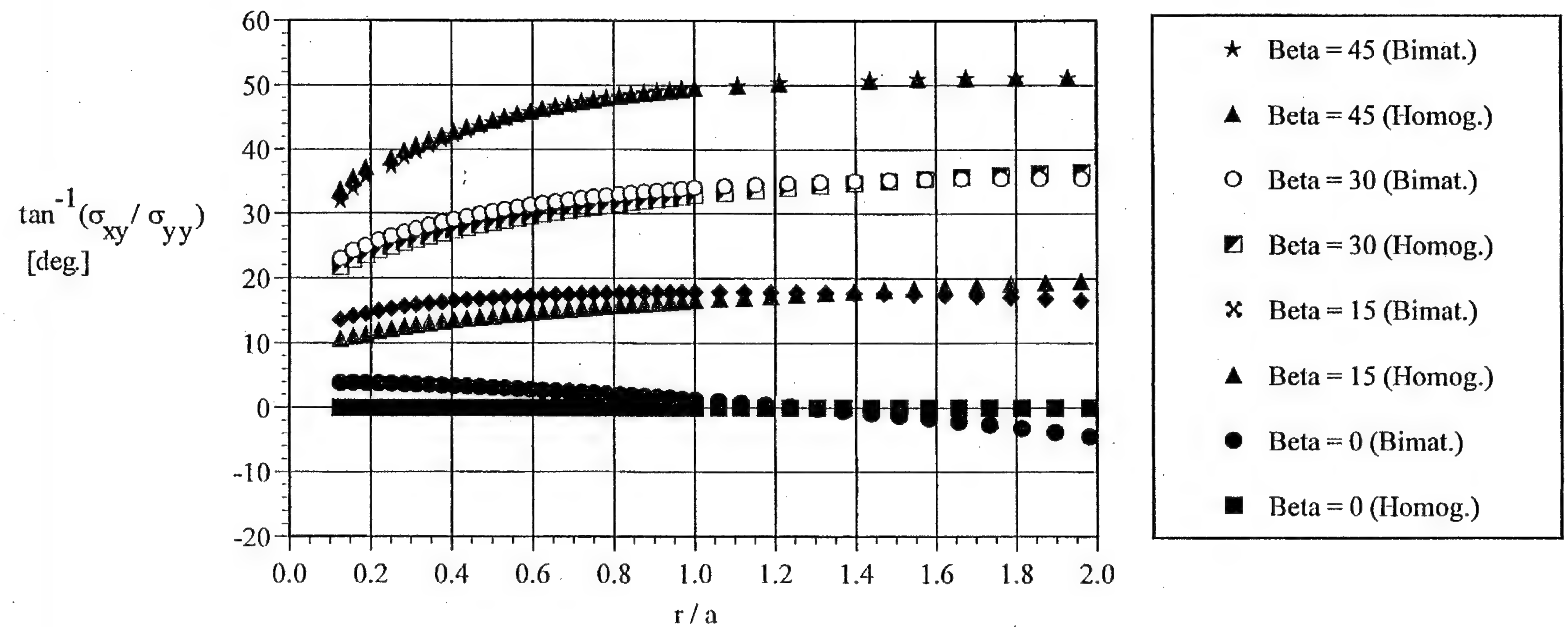
Phase Angle Extrapolation

Phase Angle is Evaluated from Bond Line Tractions Near Crack Tip



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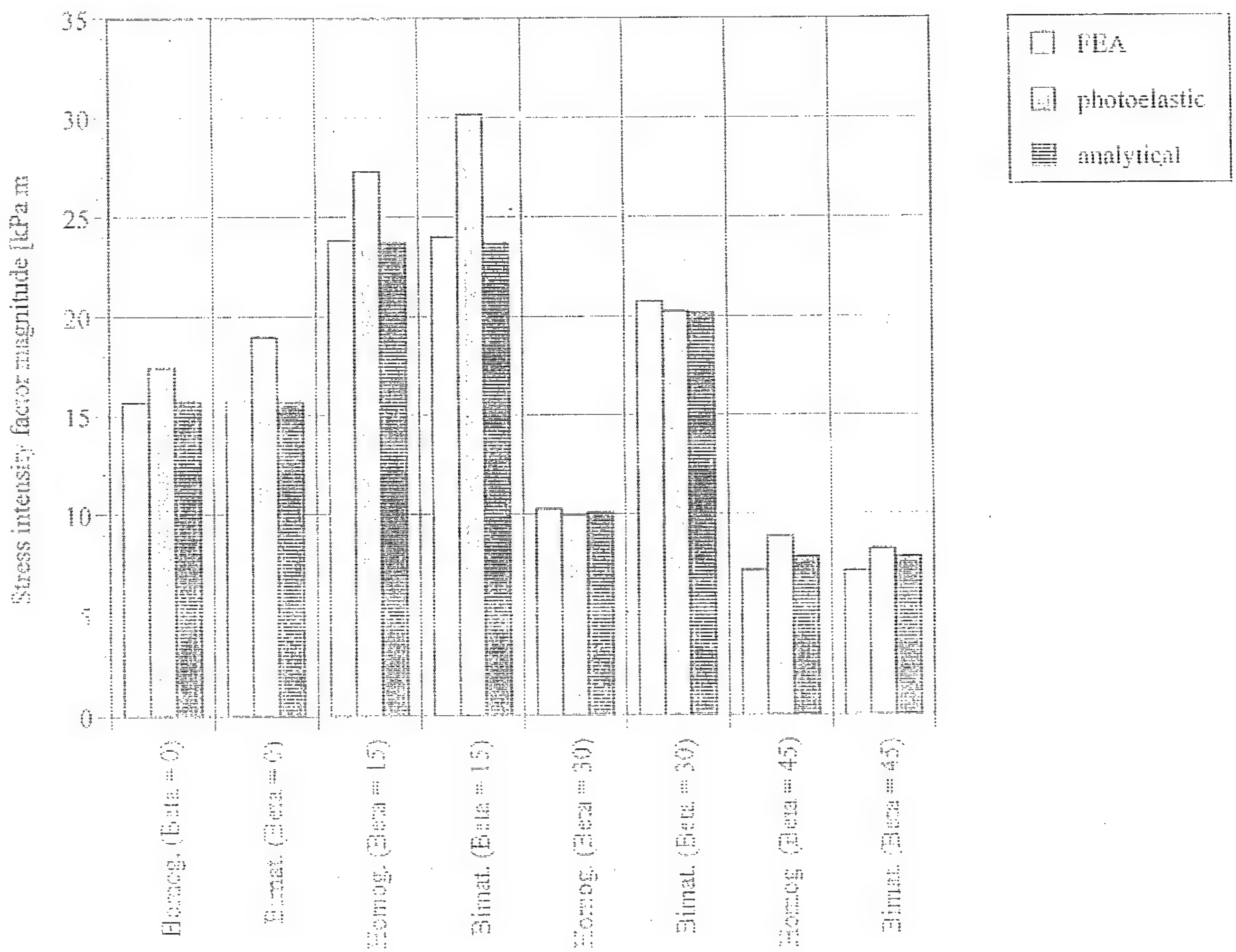
Stress Intensity Factor Magnitude Comparisons

(Comparison of Numerical and Photoelastic Results)



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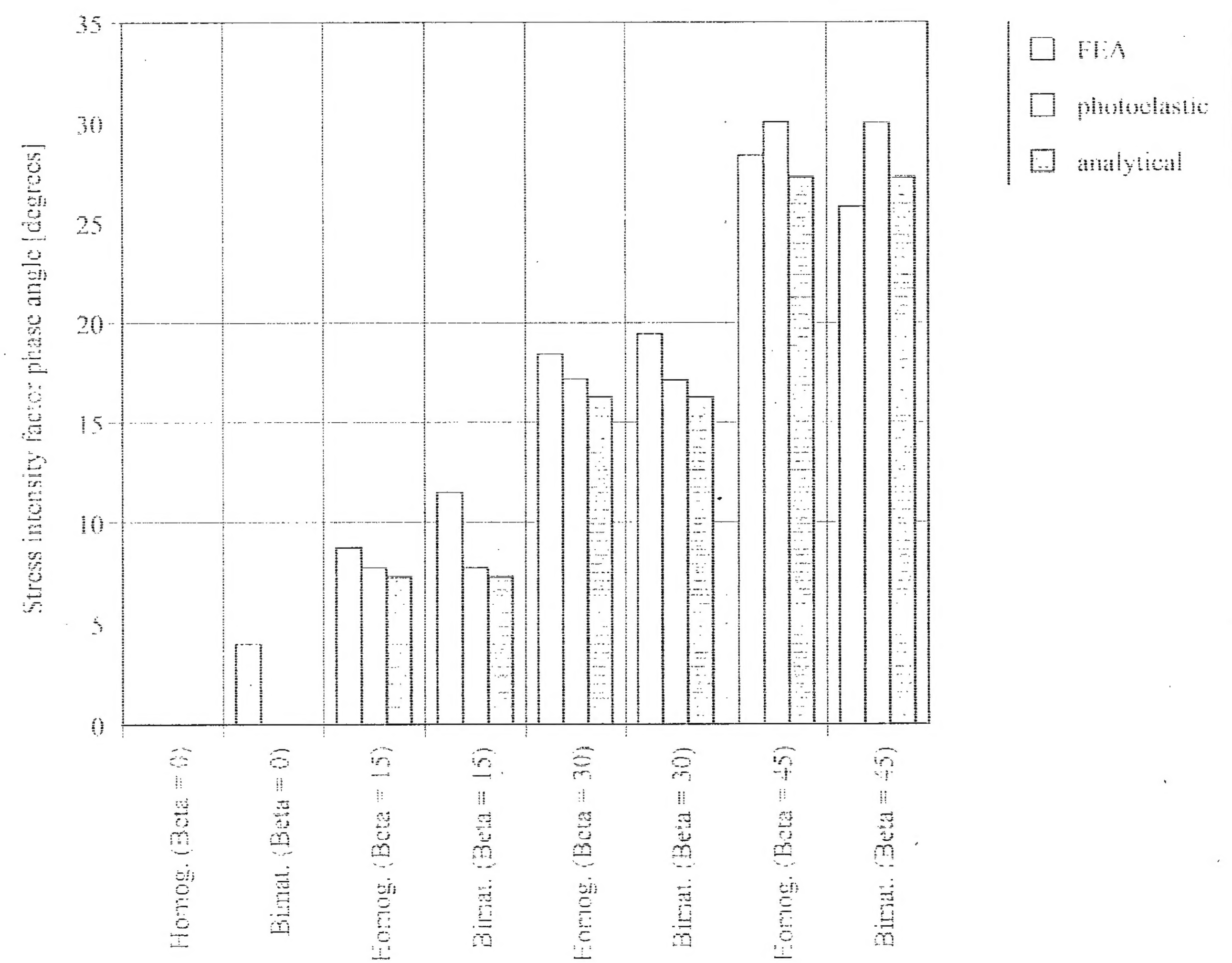
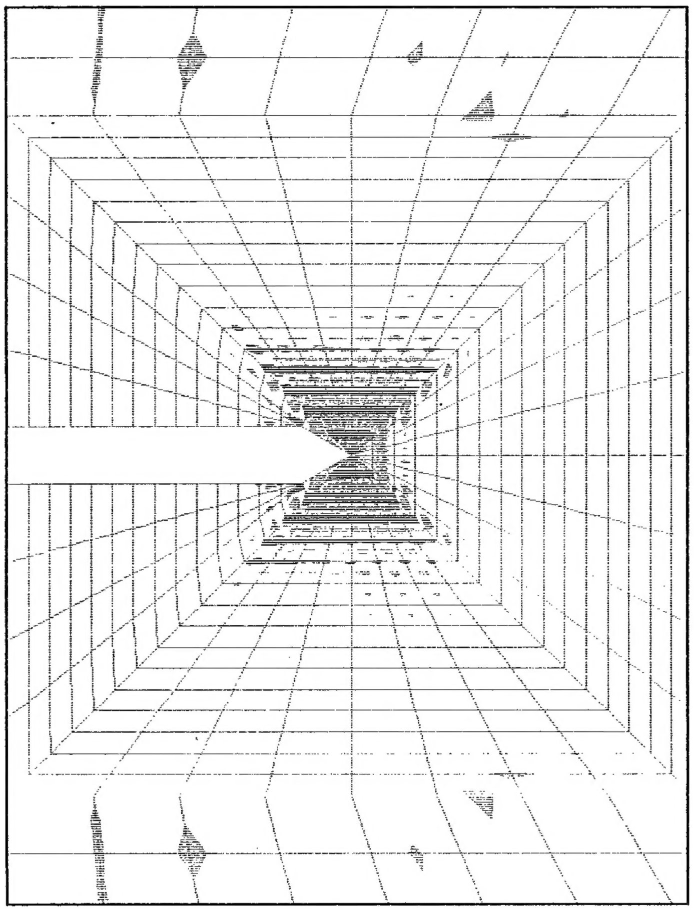
Stress Intensity Factor Phase Angle Comparisons

(Comparison of Numerical and Photoelastic Results)

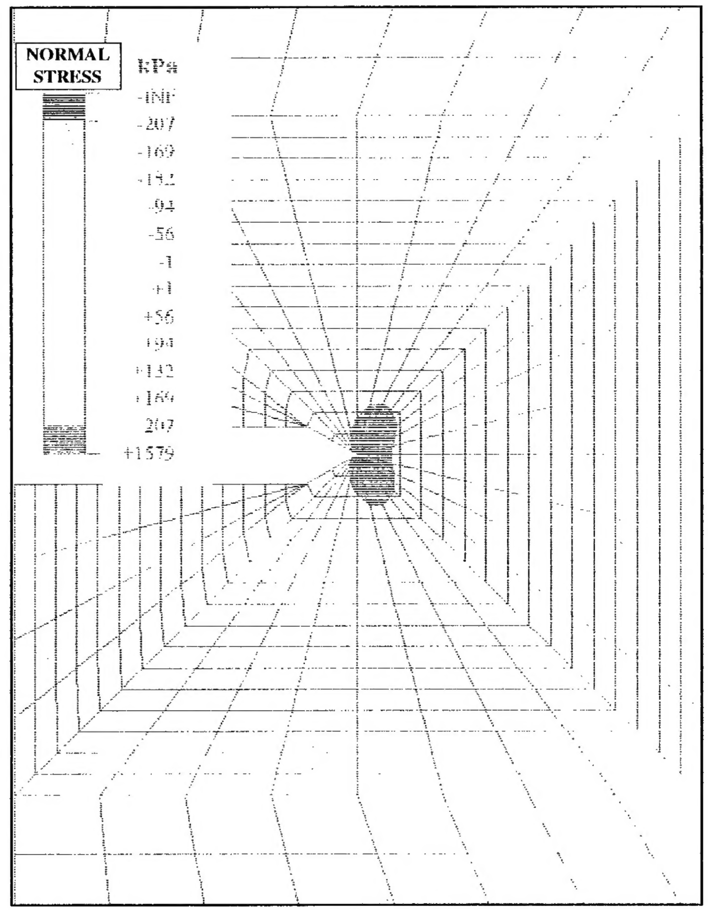


Hybrid Elements and Mixed Formulation Prevent Ill-Conditioning Problems

Conventional Formulation



Mixed Formulation



Conclusions

- Simplified field expressions can be used with incompressible bimaterials under plane strain conditions. The use of a mixed formulation and quarter point nodes are required for successful determination of the complex stress intensity factor $\vec{K} = K_I + i\,K_{II}$
- The Magnitude of the complex stress intensity factor can be determined by using area integration methods to determine the J integral and then converting J to K using effective plane strain modulus.
- The phase angle of the complex stress intensity factor can be determined by finding the limit as $r/a \rightarrow 0$ of a polynomial curve fit of $\tan^{-1}[(\sigma_{xy}/\sigma_{yy})_{\theta=o}]$ in a region near the crack tip.

- Experimental results and data - Dr. C.W. Smith, Virginia Polytechnic Institute and State University
- Funding and Computational Facilities - Dr. C.T. Liu, Air Force Research Laboratory, Edwards Air Force Base, California